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GUIDEBOOK to the GEOLOGY near READING, PA.

By

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GUIDEBOOK TO THE GEOLOGY NEAR READING, PA.

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INTRODUCTION

The Pennsylvania Topographic and Geologic Survey has from time to time sponsored educational field trips in geology. These have been held at several localities of geologic interest in Pennsylvania. Other geologic trips have been conducted annually for some years by the Field Conference of Pennsylvania Geologists. They are more elaborate than the educational trips. Because of the presence chiefly of geologists, they are also more technical. The popularity of both of these types of trips has induced the Survey to publish some of their itineraries as guidebooks to the geology of specific parts of Pennsylvania. In each bulletin a discussion of the local geology is followed by one or more detailed itineraries whereby a person or a party may form a concept of the local rock formations and visit the points of outstanding geologic interest in that particular area. The present guidebook is an example, an all-day educational trip near Reading.

Originally, the Reading trip was worked out by Bradford Willard and Forrest T. Moyer, formerly of this Survey. When it was decided to amplify and improve the schedule for publication, Donald M. Fraser was called upon to collaborate with Willard in preparing this bulletin. He has entirely rechecked the earlier work, and is responsible chiefly for those parts of this bulletin that describe the pre-Cambrian and Cambrian formations and the structural geology of the region.

The trip naturally centers about the city of Reading, county seat of Berks County. The city lies in the Great Valley where the Schuylkill, after meandering across a belt of soft shale and soluble limestone to the north, cuts a circuitous course around the hard, resistant rocks of the Reading Hills and continues southeast across lowlands of soft, red rocks. Except for a small section of the route, all points on the itinerary lie within the limits of the Reading topographic sheet of the United States Geological Survey. A few miles of the route pass through the east-central part of the Wernersville sheet which lies next west.

The geology is based upon a manuscript map of the Reading sheet now on file with the State Survey at Harrisburg and prepared by Anna I. Jonas, Eleanora B. Knopf, George W. Stose and Edgar T.

Wherry. In using this sheet, account has been taken of more recent observations published by Mr. Stose and others. Particularly, Fraser's work has been applied in determining relationships among the crystalline rocks. Willard has contributed his observations upon the Ordovician system. Account has also been taken of B. L. Miller's recent report on the limestones of Pennsylvania in general, and of the papers of R. L. Miller relating to the limestones in the Martinsburg and the Leesport limestone in particular. At the close of this bulletin (page 23) a partial list of references is appended. Most of these are cited in the text by appropriate numbers in parantheses.

PHYSIOGRAPHY

The immediate environs of Reading are of considerable physiographic interest in that here in a small space are parts of several divisions of the larger physiographic units of the eastern part of the United States. To the north, beginning with Kittatinny ("Blue") Mountain, lies the broad belt of parallel or concentrically curving mountain ridges called the *Ridge and Valley Section* of the *Appalachian Valley Province* (1, 2). It is beyond the areal limits of the itinerary of this report, but easily accessible. The Geological Survey Bulletin G14 (16) describes the geology of the upper part of the Schuylkill Valley from Leesport to Pottsville and includes this section. Bulletin G14 is complementary to the present account and may be conveniently combined therewith for a longer excursion.

The Appalachian Valley Province contains another section to the south of the mountains. This is called the *Appalachian Valley Section*. It is the broad lowland of rolling hills and meandering streams underlain by soft shale and slate and soft or soluble limestone which crosses Pennsylvania in a southeasterly direction south and southeast of the Ridge and Valley Section. The Reading Quadrangle is about one-third within this section, as its northwestern portion embraces part of the lowland which includes the city of Reading itself. Much of the adjoining Wernersville Quadrangle on the west is also in the Appalachian Valley Section. The northern part of the Valley has a slightly greater elevation than the southern, and is underlain chiefly by shale and some sandstones. The more southerly portion is a limestone valley, narrow here, but spreading east and west respectively into the Lehigh and Lebanon valleys.

The *Appalachian Mountain Province* which normally lies next south of the Appalachian Valley Province is interrupted across Pennsylvania from the Susquehanna to the Schuylkill Valley. The ancient, crystalline rocks of its mountains appear to dive underground in York and Cumberland counties and to reappear at the surface in Berks County near Reading. These re-elevated, crystalline rocks continue thence eastward as the *South Mountain Section* of the Northern Appalachian Mountain Province. The southwestward tapering end thus produced is called the *Reading Prong,* terminating in the Reading Hills.

South of the Reading Hills, or, where they are absent, of the Appalachian Valley with its limestones and shales, lies another major physiographic unit. This is the *Piedmont Province* and embraces much of southeastern Pennsylvania to the *Coastal Plain Province* crossed by the lower reaches of the Delaware River. In the Reading Quadrangle the Piedmont Province is represented by its northernmost Section, the *Triassic Lowland.* This is a broad band of relatively low terrane underlain by soft shale, sandstone and conglomerate generally, with here and there small hills and ridges which mark the presence of harder rocks of igneous origin.

The physiographic features just outlined have passed through a long history dealing with their beginnings, development and final arrival at their present status. This statement probably will be appreciated better when one understands more fully the nature of the rocks of the region and its more ancient history.

Long ago, even as geologists reckon time and earth history, the then flat-lying beds of rocks of Pennsylvania were subjected to a process of horizontal compression, a squeezing as in a mighty vise. The more resistant, stronger rocks were bent or folded until they lay as gigantic, frozen waves. Some of the brittle members broke and moved about or slid over each other as cakes in an ice-pack driven together by wind and tide. The weak, non-resistant rocks were smashed, and crushed.

Some rocks are hard and resistant to weathering and erosion, others because of their less sturdy nature are easily worn or eaten away by the elements. Nevertheless, given sufficient time, all rocks, even the toughest, will theoretically be worn down *almost* to sea level. They cannot go lower because they are planed off, principally by running water. Naturally, when the land has been worn down very low, the streams become extremely lazy, and no longer strongly rasp and scrape off the surface rocks. Such a condition of stalemate was reached long ago in Pennsylvania. The land surface so made is called a *peneplane,* that is, it was worn down almost to a plane.

But, beneath this peneplane were the roots of the folded and broken strata which had been formed and crumpled long ago. Because the ancient "rock waves" trended generally northeast by southwest, there must have lain beneath the peneplane a succession of northeast by southwest trending bands of alternately hard and soft rocks, not unlike the grain in a wooden plank. Suppose, for some unknown or not readily understood cause, our peneplane with its hidden bands of resistant and non-resistant rocks were gradually elevated as a whole, let us say, to at least the present heights of Kittatinny Mountain and Mount Penn. As the former is higher than the latter, we may even assume our upraised surface to have been tilted gently toward the Atlantic Ocean.

The lagging rivers and creeks awoke to new life and commenced to scramble seaward down the new slope. Their rejuvenation meant renewed powers of rock erosion, and transportation eastward of the products of erosion. Such big streams as the Schuylkill proceeded to cut through hard ribs and softer bands alike with almost

equal ease. Weaker streams, as Maiden and Tulpehocken creeks, had no such power. What was the combined result? Where the Schuylkill encountered resistant strata such as those to be seen now in Kittatinny Mountain, it dug its bed down through them. Southeast of Reading it did, to be sure, dodge around the end of the hard rocks of Neversink Mountain, but in general the Schuylkill maintained much the same course which it had followed in its meanders inherited from the old, peneplane days. Not so the smaller streams. Too weak to file notches and gaps in the hard rock bands, they soon adapted themselves to courses of least resistance offered by the soft or soluble strips of shale and limestone. Thus, owing to the manner of adaptation to previously existing conditions, the master and tributary streams working in turn across and along hard and soft rock bands, etched out the soft beds so that the hard rocks stand up today as mountain ridges and isolated patches of higher ground. The lowlands are all underlain by soft or soluble strata.

Visit the top of Mount Penn on some bright forenoon when a brave northwest wind has swept away the smoke of the city. Turn your attention to the northern horizon. In the distance is the long, even skyline of Kittatinny Mountain. The water gap of the Schuylkill beyond Hamburg notches it. Otherwise, it is remarkably even. It is a trace of the old peneplane, left by the process of stream etching. Between Kittatinny Mountain and Mount Penn, a broad lowland intervenes, underlain in its higher levels to the north by shale and in its lower terrane to the south by limestone. It is crossed here and there by the lesser streams. See how the limestone valley is flat-

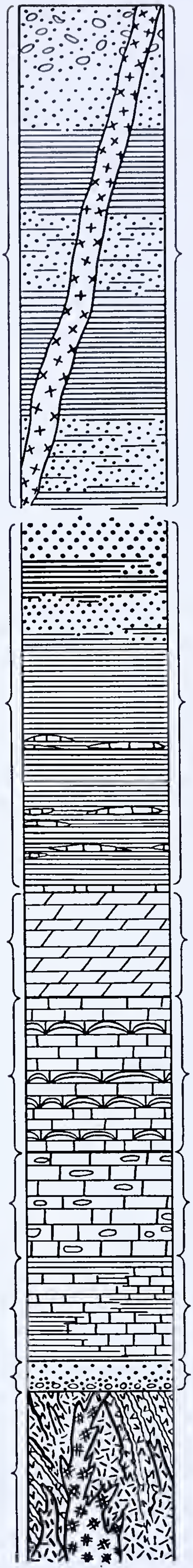
Figure 1—Lake Ontelaunee from the dam. The lake occupies a portion of the western part of the limestone valley. The scarp and higher, partially wooded ground in the distance are underlain by the Martinsburg formation. The change in topography is, therefore, due to the difference between the soluble limestone and the insoluble shales and sandstones beyond.

Figure 2—View in the Triassic Lowland near Baumstown, southeast from Reading.

floored from southwest of Reading northeastward in a broad curve past Ontelaunee Reservoir and away toward Kutztown. It is bordered on the north and northwest by low, rolling hills of shale, but ends abruptly on its south and east sides against the hard rocks of the high Reading Hills of the Reading Prong. From Neversink Mountain we may again glimpse the limestone and shale valley, but facing about and looking south and east the Triassic lowland is at our feet. The name is bestowed by virtue of the rocks (the Triassic system) which underlie the surface. Being mostly non-resistant shale and soft sandstone, these have worn away as a lowland, but Kinsey, Gibralter, Highs and other small hills and ridges rising from its floor, mark where hard, igneous rocks (lava) cut through the soft beds. Resisting erosion better than the shale and sandstone, they form ridges and knobs.

STRATIGRAPHY

The rocks of the Reading area are many and of diverse sorts. We shall describe briefly the important rock kinds which are to be seen on the excursion outlined in this guidebook. A few others are mentioned for completeness. Such a description of the formations is embraced in the *Stratigraphy* (i.e. broadly, the study of the strata) of a region. As the rocks are of several different ages, we shall take them up in ascending order from the oldest to the youngest in the sequence in which we might expect to find them if they were all lying flat one on top of another in the succession in which they formed and we could study them from the bottom to the top of a shaft driven perpendicularly through them. The sequence is diagrammed in Figure 3.



Unconsolidated material, principally stream valley terraces.	
PLEISTOCENE AND RECENT	
TRIASSIC SYSTEM	
Brunswick formation 5000 feet (?)	Red sandstone, shale and conglomerate, cut by basic igneous rocks.
ORDOVICIAN SYSTEM	
Martinsburg formation 3000-4000 feet	Dark shale with more or less calcareous sandstones and thin lenses of platy limestone locally.
Leesport formation 50-60 feet	Thin, platy limestone, lithology variable.
Beekmantown formation 1000 feet	Massive, blue-gray, magnesian limestone.
CAMBRIAN SYSTEM	
Conococheague formation 1000-1500	Blue-gray, sandy limestone with *Cryptozoön* beds.
Elbrook formation 1000 feet	Massive, blue-gray, magnesian limestone with chert bands.
Tomstown formation 800-1000 feet	Impure, dolomitic limestone and interbedded shale.
Hardyston formation 300 feet	Sandstone, quartzite and conglomerate.
PRE-CAMBRIAN ROCKS	
Pegmatites	
Byram granite and granite gneiss	
Pochuck gneiss	

Figure 3—Geologic column for the Reading area.

PRE-CAMBRIAN FORMATIONS

Geologists divide the long succession of rocks formed through the ages of earth history into several parts called *systems* (1, 15). Each system is divided into *formations* or lesser units. Geologic time is broken up into a succession of very large units called *eras*, and the eras in turn are made up of *periods*. A period is the portion of geologic time during which a particular system of rocks formed. Thus the Cambrian system formed during the Cambrian period. The Cambrian is the oldest system of rocks which contains abundant fossils. All of the still older rocks are, for convenience, spoken of collectively as the pre-Cambrian.

Three rock types appear in the exposures of the pre-Cambrian formations. These are confined in our area to the Reading Hills. They are dark-colored, granulose or gneissic rock (the Pochuck) and two light-colored types, one a finer-grained granitic rock (the Byram), and the other, coarser grained, a pegmatite.

Pochuck gneiss. The Pochuck gneiss is a dark-colored, dense rock composed of plagioclase feldspar and hornblende with pyroxene or biotite appearing in many places. When found in field exposures it usually has a streaked or banded appearance. The grain is commonly from 1 to 3 millimeters in diameter, and the material typically shows a greenish-black to dark salt-and-pepper color. This latter effect is the result of mingling dark-colored hornblende, pyroxene or biotite with light-colored plagioclase.

This formation is regarded as the oldest in the district. The Pochuck today is a metamorphic rock called a gneiss. It has been produced by recrystallization from a previously existing igneous type of material. This earlier igneous material may have been an intrusive body injected into other rocks or it may have been formed by the accumulation of lava flows at the surface. Whatever its origin, it has since suffered great changes. Some of these changes were the result of increased temperature and pressure when the rock body was buried under later formations. The reorganization of the original minerals into new crystals having a greater tendency to parallel orientation developed the gneissic banding or streaking observed in the formation at present.

The minerals of the Pochuck gneiss include plagioclase feldspar, hornblende, pyroxene and biotite, as the more abundant minerals. Others occurring in smaller percentages include magnetite, titanite and apatite.*

At some period later than the development of the gneissic structure in the Pochuck, the area of the Reading Hills was invaded at depth by a great mass of molten rock material known as a magma. This magmatic material which later solidified to form the Byram granite or granitic gneiss was able, by virtue of its chemical activity, to dissolve or assimilate large amounts of the older rock materials of the Pochuck type. We, therefore, find various gradations existing between the

* When the rock alters, the secondary minerals most commonly developed are epidote, uralite, and saussurite.

dark-colored Pochuck and the lighter-colored granite of later age. These relationships will be discussed in more detail under the description of the Byram granite or granite gneiss. The type of rock material resulting from the assimilation process has been described (4) in the area of Macungie southwest of Allentown.

Figure 4—Photomicrograph of the Pochuck gneiss. This phase of the Pochuck is typical. The solid black grains and unbanded gray grains are hornblende. The banded, darker grains such as those at the center top and center bottom are plagioclase feldspar as are most of the lighter grains in the field. The larger, white grain at the right of the picture is quartz. This specimen shows that the rock has been crushed but has not suffered decomposition of the mineral grains. Magnification 24 ×.*

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* The photomicrographs, (Figures 4, 5, 6, 7 and 8) which are photographs taken through the microscope, show the different minerals found in some of the rocks in the Reading area. In the hand specimens of the rocks these minerals are about as large as grains of sugar or some of them as large as the head of a match but are difficult to determine in such small sizes. With thin slices of such rocks one may distinguish the different minerals under the microscope by their color, the type of fracture or cleavage they possess and other features which are clearly seen when they are magnified. The photomicrographs are shown in the illustration with a brief description of the different minerals determined.

Figure 5—Photomicrograph of the Pochuck gneiss. This shows a biotite bearing phase of the Pochuck gneiss. This material is much less common in the Pochuck but still occurs in many places in the Reading Hills. The black grains are biotite. The lighter areas are plagioclase feldspar of approximate oligoclase-andesine composition. Magnification 24 ×.

Byram granite or granite gneiss. The light-colored granitic rocks of the area range from those that lack parallel arrangement of grains and are, therefore, termed massive, to those types having a parallel arrangement, which are termed gneissic. These granitic rocks are all included under the Byram granite or granite gneiss and in their purer form are composed of alkali feldspar and quartz. The characteristic feldspars are microcline and microperthite, an intergrowth of orthoclase and albite. In the purer types, the Byram contains small amounts of the accessory minerals apatite, zircon and magnetite but the percentage of dark-colored grains is extremely small. The alteration products are chiefly kaolin and sericite. The more massive types are the result of the solidification of liquid rock material in which streaks were not developed by flowage or the selective orientation of inequidimensional grains. The forms which are more properly termed granite gneiss possess a parallel arrangement of mineral grains, or distinct streaks or bands as the result of the grouping of different

colored crystals into layers. The variations from the massive to streaked or banded types are due to two causes primarily. The first of these is the orientation of darker grains which have been derived by assimilation from the Pochuck material and may represent the remnant of the original streaking in the Pochuck gneiss. The second cause of parallel arrangement is due to flowage during the consolidation of the mass. Such movement within the body orients inequidimensional particles parallel to a plane or a direction much as toothpicks would be oriented on the surface of moving water. The first of these parallel arrangements is considered a residual structure from the original rock. The second is regarded a primary structure of the granite gneiss.

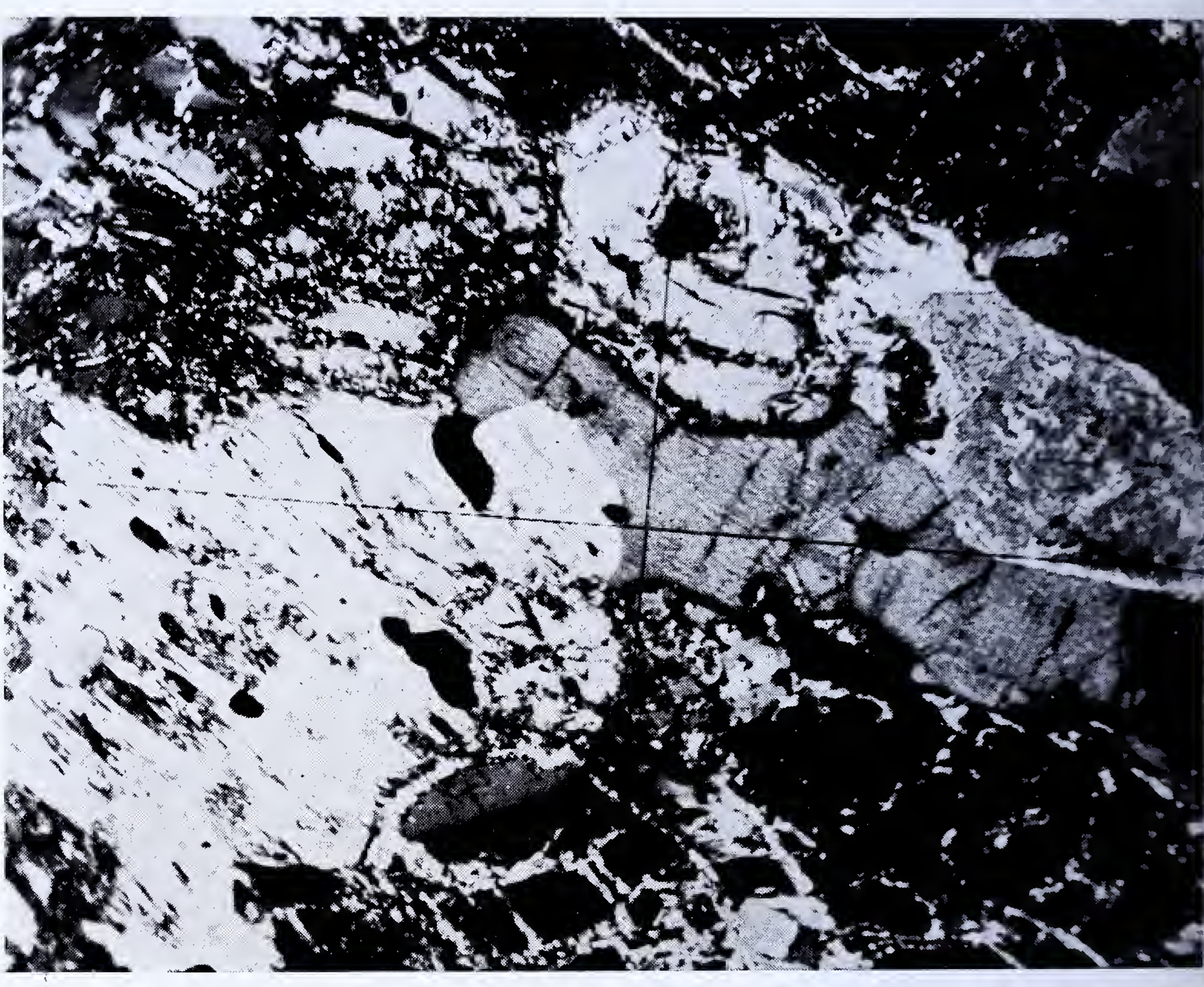

Figure 6—Photomicrograph of the Byram gneiss. In this figure, the Byram gneiss is shown with assimilated materials from the Pochuck gneiss. The large grain at the lower left having fibrous structure is altered feldspar. The long, gray grain extending from the center to the right-center is hornblende. Broken grains at the upper left and center, and lower right and center are quartz. This specimen has been crushed, and the minerals have been partially altered. The streaks composed of small grains cutting the larger particles are chiefly sericite formed from the decomposition of the original minerals. Magnification 24 ×.

Probably the most striking feature of the exposure of the pre-Cambrian rocks in this area is the extensive and intimate mixing of the lighter and darker types. In most places the Pochuck gneiss shows more or less invasion by the later granitic material. We can best visualize the conditions under which these relationships were brought about if we mentally picture the conditions that must have existed some hundreds of millions of years ago when the Byram granitic material invaded the Pochuck. During that remote time the Pochuck gneiss was buried at a depth of at least several thousand feet by overlying formations. The Byram magmatic material coming up from greater depths in the earth's crust moved slowly by working along fractures in the other rock masses and by dissolving (assimilating) the rocks into which it was encroaching. The presence of a great mass (which in the Reading Hills district was surely many cubic miles in volume) in the vicinity of the Pochuck material raised the temperature of the older rocks, and because of elevated temperature and the chemical activity of the invading material, reduced the older mass to a viscous or plastic condition, at least close to the contact with the invading magma. Consequently, the invading material was able intimately to penetrate the older rocks.

Examining the contact relation between the formations we find variations in the relative abundance of the materials derived from the two rock types. In some places the older, darker gneiss was completely incorporated in the later, liquid, magmatic material. The subsequent solidification of such masses has given rise to rocks whose mineral composition is intermediate between the original Pochuck gneiss and the later Byram granite. In other places the older, basic gneiss was parted along numerous planes, and the Byram granitic material invaded these zones of weakness to produce lighter-colored layers of granite alternating with the original Pochuck layers. In still other exposures we find relationships which indicate that the granitic minerals were introduced in a dispersed form into the basic gneiss, resulting in patches or disseminated grains of the granite minerals surrounded by the minerals of the Pochuck. We may, therefore, in our visualization of the conditions at this early time, consider that all stages of mixing existed from 100 percent Pochuck to 100 percent Byram. Between these end members it should be possible to find specimens showing all gradational percentages.

If the Pochuck gneiss had been a relatively cold body of rock which was invaded by the later Byram granite only along fracture planes we would find clean-cut dikes of the later material with little gradation between the two. It is because such conditions rarely exist, and because the more intimate mixtures have affinities characteristic of each of the pure types that we are able to state that the invasion occurred at profound depth and that the Pochuck was likely reduced to a near-liquid if not actually fused condition in many places.

Pegmatite. Accompanying and following the granitic invasion by the Byram of the Pochuck gneiss, masses of magmatic residuum in the form of quartz-feldspar-rich material cut both of the older forma-

tions. These masses, which are usually composed of potash feldspar and quartz, are found cutting the other rocks both as relatively well-defined dikes and as quite irregular bodies gradational into the wall rock, but distinguished from that host rock chiefly by virtue of the coarser texture of the introduced material. The pegmatites exposed along the route of this guide book range from white to pink and commonly show crystals of a larger size than those characteristic of the Byram granite. The diameter of the larger crystals may approach several inches; in fact, pegmatites in other districts exhibit crystals many inches or even feet in diameter. In some of the pegmatites of the Reading Hills, one finds in addition to microcline and quartz, the minerals: muscoviate, biotite, garnet and tourmaline.

The origin of the pegmatites is thought to be from the last material of the magma to solidify. In this end stage liquid we would expect to find a concentration of materials of magmatic crystallization, some of which would be the more volatile constituents. It has been found from observation of volcanic areas and also from laboratory investigations that the volatile materials of magmas include boron, carbon dioxide, water vapor and fluorine, one or more of which may appear in the minerals crystallizing from the end stage liquid of a magma. It is for this reason that pegmatites contain minerals which often carry one or more of these elements. Furthermore, the coarser texture of the pegmatites is at least in part due to the presence of some of these more volatile constituents, which are thought to allow pegmatitic bodies to retain low viscosity even at considerably reduced temperature.

CAMBRIAN SYSTEM

Cambrian rocks of the region about Reading are of two major types: quartzite and sandstone, and limestone and dolomite.

The oldest Cambrian formation in the area is the Hardyston (sometimes called the Weverton) quartzite which is overlain successively by the Tomstown dolomite, Elbrook limestone and Conococheague limestone. In the Reading area and northwestward toward Allentown, Stose and Jonas (13) have mapped both Elbrook and Conococheague, but Miller (7) in the Allentown-Bethlehem area has considered all the Cambrian limestones above the Tomstown to be best represented as one formation, the Allentown limestone.

Hardyston quartzite. The first deposit of the Cambrian period in this area was an accumulation of pebbles and sand grains composed chiefly of quartz but with some feldspar. The sand was in greater abundance than the pebbly material. The compaction and hardening of these sediments into rock produced the Hardyston formation. The quartizitic character of this material is the result of the firm cementation of the sand grains and pebbles by silica cement. The dense, brittle varieties appear where the process of cementation was complete and all of the pores between the grains were filled. The looser phases of the Hardyston still retain much of their original pore space or they may have been nearly or completely indurated by cementation but

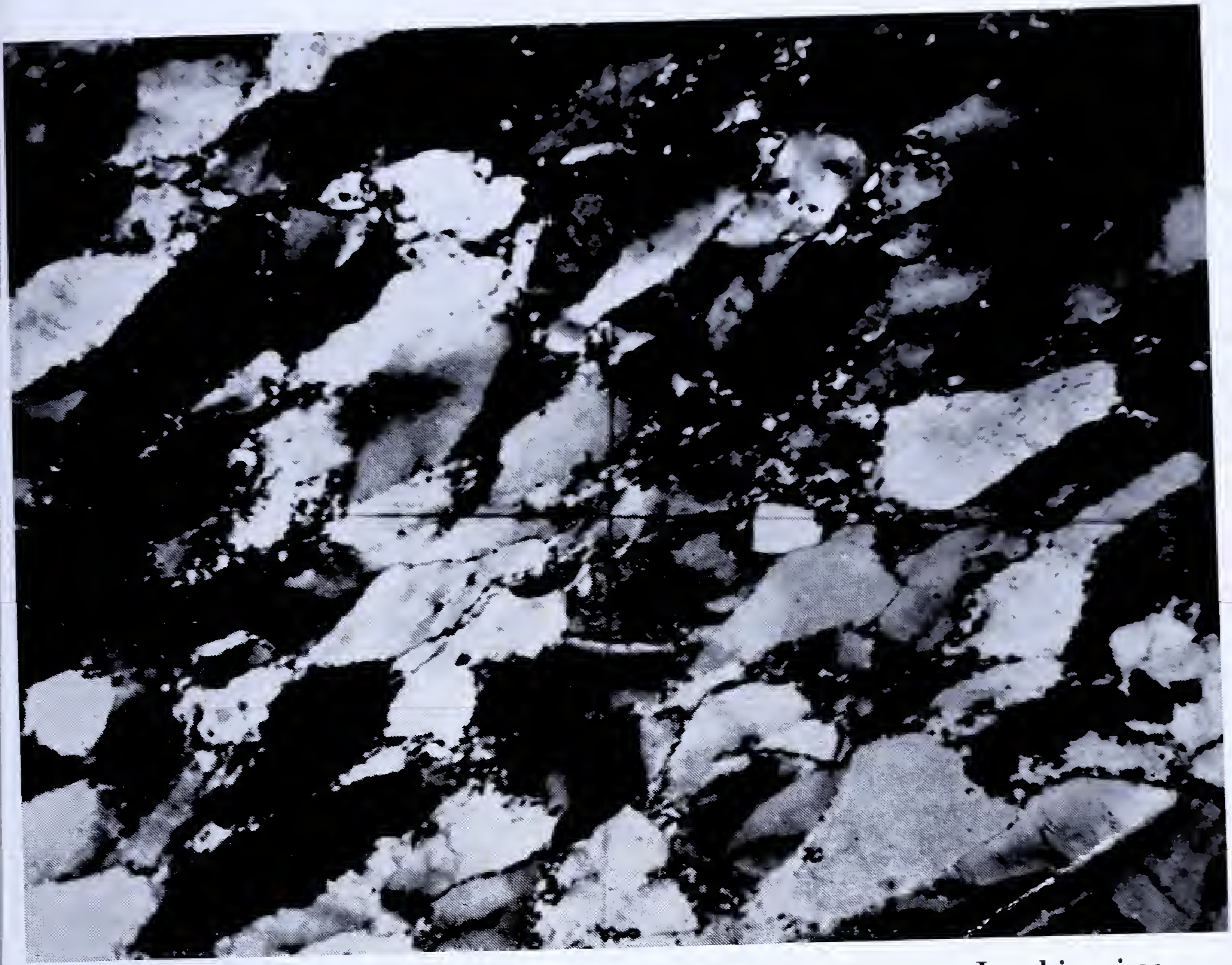

Figure 7—Photomicrograph of the Hardyston quartzite. In this view, most of the grains of the Hardyston quartzite, whether light- or dark-colored, are quartz. They have been stretched so that most of them are longer in one direction than the other. The small granules surrounding them have in part been formed by crushing the edges of the larger grains. This phase of the Hardyston in a hand specimen is dense and glassy. Magnification 24 ×.

have since suffered decomposition of some of their mineral grains, chiefly perhaps the feldspars.

The Hardyston varies. It may range in structure from dense, cherty, massive types into porous, friable forms. In color it ranges from blue-gray to yellow or tan. The best developed Hardyston observed on the route of this guidebook is along the ridge road in the vicinity of Tower Hotel. In numerous outcrops here the formation occurs in thin to heavy beds of gray to tan sandstone and conglomerate which have mostly been well cemented by silica to produce dense, glassy quartzite. In places where the sandstone is only partially cemented and somewhat porous it resembles sugar. A few miles to the north in the slopes east of Temple the Hardyston is very porous and easily crumbled. The thickness varies and probably approaches 300 feet at its maximum. The only fossils are the worm borings called *Scolithus*. These are recognized as straight or slightly curved, rod-like objects with diameters of 2 to 15 mm. They are distinguished

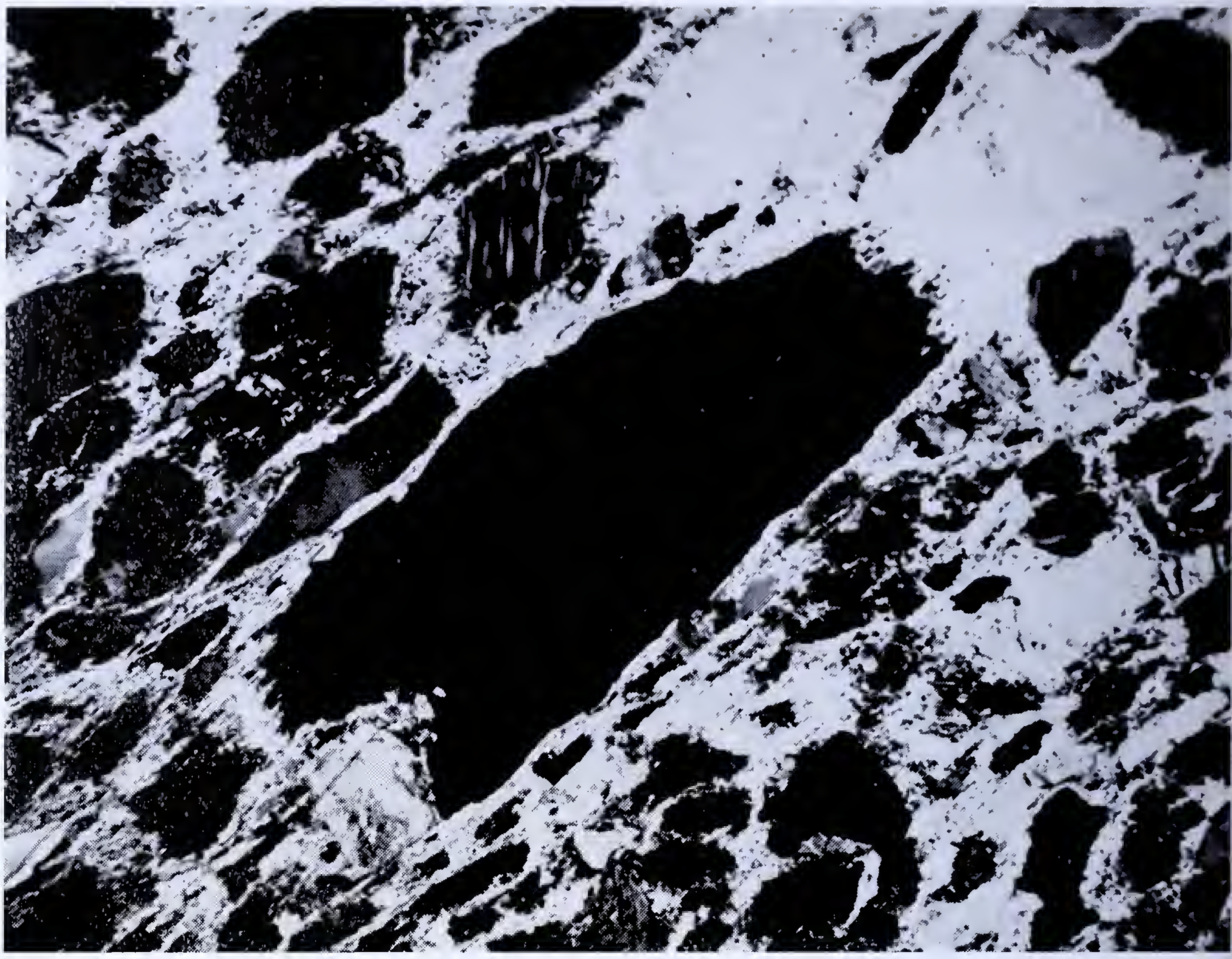

Figure 8—Photomicrograph of the Hardyston quartzite. The black grains in this view of the Hardyston are for the most part quartz. The streaked or rudely banded grains such as the one just above the large black grain in the center are feldspar. Surrounding all of the larger particles is an aggregate of fine fibres or scales of sericite which shows up as lighter material in the picture. The sericite is formed in part from the alteration of the grains of the rock and in part from the breaking down of the cementing material. This type of Hardyston in hand specimens shows a less massive character than the material illustrated in Figure 7, and in addition many of the fracture surfaces, due to the presence of the sericite, are talcy in appearance and feel. Magnification 24 ×.

from the surrounding rock by difference in color or texture of the material which fills the ancient burrows.

Tomstown dolomite. The Tomstown dolomite is a gray, magnesium-calcium carbonate rock containing many shaly layers. Its thickness has been estimated by different workers as 800 to 1000 feet. Overlying the Hardyston sandstone and underlying the purer Elbrook limestone, it may be regarded as transitional with its shaly layers ranging toward the clastic material of the older beds and its dolomitic layers more closely resembling the calcium and magnesium precipitates of the limestone which follows it. As this formation does not appear along the route, it need not be described further.

Elbrook limestone. The Elbrook limestone is not exposed along the route of this guidebook and so need be described only briefly to complete the section. Stose (11) named this formation from Elbrook in the Chambersburg quadrangle, Franklin County, Pennsylvania, and described it as:

> "Massive, bluish-gray, magnesian limestone, with numerous thin layers and nodules of chert and beds of shale, possibly 2,000 feet in all, compose the . . . formation. Red and green shales are present in the middle of the formation, and beds of sandy limestone, which in places form low ridges, occur higher in the section . . ."

In the Reading area, it is likely that the Elbrook is thinner. Stose suggests about 1,000 feet as its thickness here.

Conococheague limestone. The Conococheague limestone is a thin-bedded, blue to blue-gray limestone having numerous sandy layers that weather on long exposure so as to stand out in relief, producing a ribbed effect. The layers are dense and compact and contain very few fossils except the calcareous alga, *Cryptozoön,* which appears as concentric layers in the beds. The individual masses or "heads" range from a few inches to a few feet in diameter. Many are from 12 to 18 inches across. Cross-bedding in the sandy layers and ripple marks on the bedding planes indicate that the material of the Conococheague was largely deposited under shallow water conditions. Similar features of earlier formations as well as their lithology bear out the contention that the sedimentary rocks of the Cambrian period in this area were for the most part laid down in shallow water as near shore accumulations. The part of this series considered as Conococheague is probably between 1,000 and 1,500 feet thick, although a complete section cannot be measured on the route of this trip. In south-central Pennsylvania in the Chambersburg quadrangle, Stose (11) gives a thickness of 1,635± feet for a measured section, and in the Doylestown quadrangle east of the Reading area the same writer (3) estimates the thickness to be nearer 900 feet.

ORDOVICIAN SYSTEM

In central Pennsylvania, a very great thickness of rocks has been piled up between those assigned to the Triassic system (see below) and those to which we now turn, the Ordovician system, which succeeds the Cambrian system just described (1, 15). These post-Ordovician and pre-Triassic beds include the Coal Measures and other systems, the Mississippian, Devonian and Silurian. However, in southeastern Pennsylvania most of these rocks, if they were ever present, had been worn away long before the Triassic beds formed. Consequently, Ordovician and older rocks are overlain by much more youthful ones, with a great lost interval between.

Beekmantown limestone. The northwestern half of the limestone valley at and beyond Reading is underlain by a formation called the Beekmantown limestone. It is about 1000 feet thick and consists of gray to blue-gray limestone, most of which is high in magnesia, al-

though beds of purer calcite occur. The rock weathers to a mottled appearance. It has yielded a few fossils in Pennsylvania, chiefly large sea snails named *Maclurites* and occasional remains of ancient, cuttle-fish-like forms called *Orthoceras*. In the vicinity of Reading the Beekmantown limestone may be studied in several operating or abandoned quarries.

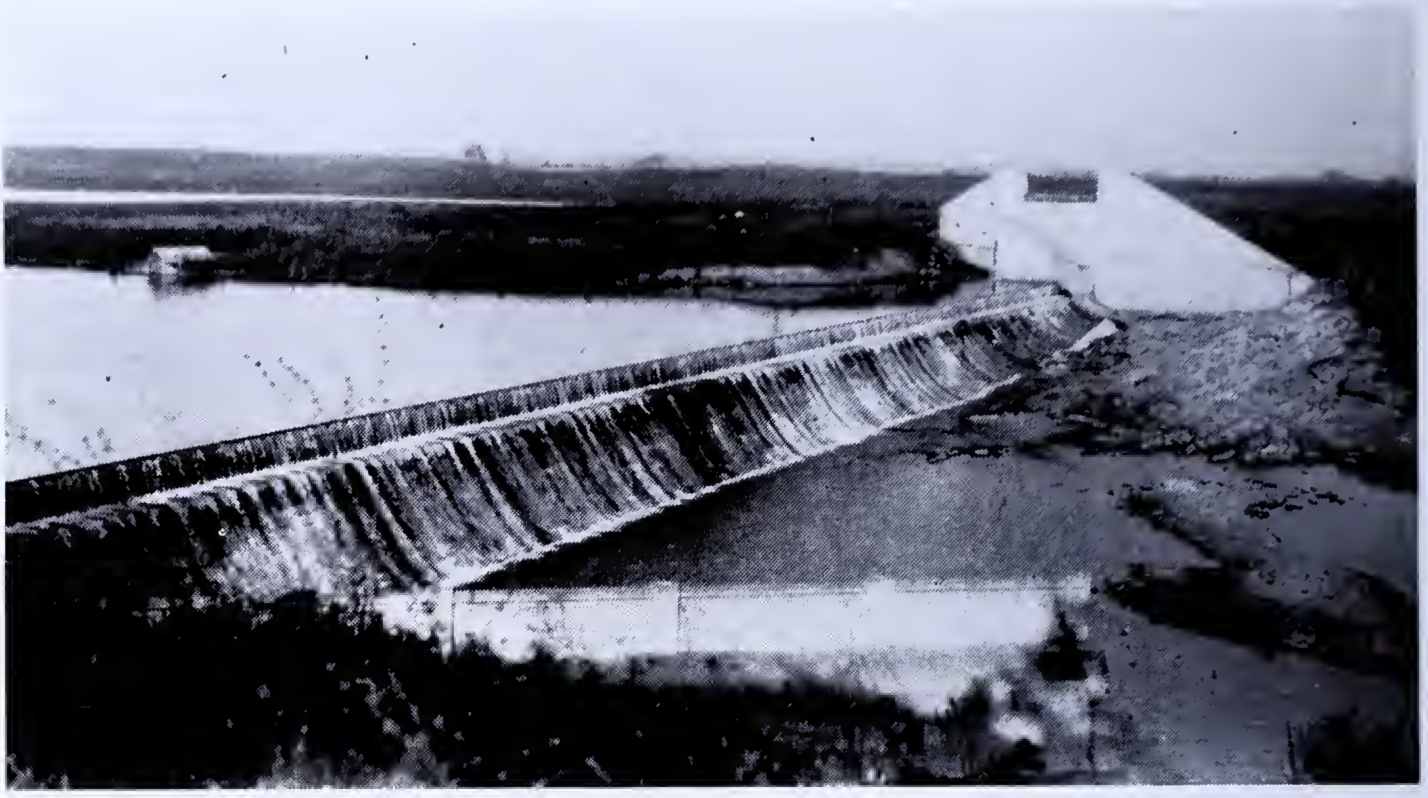

Figure 9—Lake Ontelaunee dam. Below the dam are exposed the up-turned edges of the Beekmantown limestone.

Leesport limestone. Above the Beekmantown limestone lies the Leesport limestone also of Ordovician age. Toward the end of our tour we shall stop at a railroad cut at West Leesport to examine this unit at its type locality, that is, the place from which it takes its name. There, the shales of the succeeding Martinsburg formation grade down into limestone of varying characteristics, but dominantly platy like those of the Martinsburg itself *(q.v.)*. In fact, the similarity leads some to call this merely such a limestone, whereas others consider it a separate formation by itself lying between the youngest Martinsburg and the older Beekmantown (14, 10). No fossils are known in these beds, which are about 50 to 60 feet thick at West Leesport.

Martinsburg formation. The Ordovician system of rocks, as with other systems, is divided into several large units of similar or closely related strata which are called formations. The highest Ordovician beds we shall encounter are known as the Martinsburg formation. This overlies the Leesport and Beekmantown limestones. In the northwestern part of the Reading Quadrangle and at a few other scattered exposures toward the southeast, this formation crops out. It consists of much dark gray to black shale, which, in Lehigh and

Northampton counties, has been squeezed so that it has turned into slate. Among the shale beds there are many sandy layers, especially in the upper part beyond our area, north of Hamburg (*cf.* Bulletin G14, 16). Most of these sandstones have the grains cemented by calcite, a mineral that is rather easily dissolved. Because of this condition, the sandstones though apparently mighty, weather easily to loose grains and fail to form mountains or even hills. Another feature of the Martinsburg is thin limestone beds among the shales (9). Usually, these are of two kinds. One variety consists of thin ("platy") limestone strata separated by shale beds. The other, called *breccia,* is a mass of broken limestone fragments cemented into a solid bed.

The Martinsburg is usually reported as being very thick, but the shales have been so crushed and crumpled that accurate measurements are extremely difficult if not impossible to make. A conservative figure would place the thickness at 3,000 to 4,000 feet, but some would call this far too small. Fossils have been found in the Martinsburg, but in the region we shall visit none are known to occur. They may have once been present here, but the rocks have been so broken and squeezed that all traces have been destroyed.

TRIASSIC SYSTEM

After the Ordovician system of rocks, there is a great gap in the stratigraphic sequence, as already mentioned. Next, the red beds of the Triassic system which represent part of the rocks of an era called the Mesozoic were laid down. It was that time of earth history when the land, sea and air were populated by reptiles of all shapes, sizes and temperaments. Furry creatures were almost unknown, and feathers had not come into fashion as yet. The dinosaurs were "lords of creation." Their foot-tracks are known from the red Triassic shales which stretch in a broad band across Pennsylvania from the Delaware Valley above Philadelphia southwestward through Gettysburg. These strata are well represented in the Reading Quadrangle, and we shall see several examples of them on the tour.

Brunswick formation. The Brunswick formation is the youngest of the Triassic system in eastern Pennsylvania, and it embraces all of the Triassic reds beds in our area. The greatest known thickness of these beds is said to be several thousand feet (16,000 according to some students), but it is very difficult to tell the thickness. It is a monotonous succession of red shale, red sandstone, and, locally, conglomerate in which last many individual pebbles are of limestone enclosed in a matrix of red mud cement. This handsome stone is popularly called "calico rock." Probably the actual thickness of the Brunswick formation in the Reading area is far less than 16,000 feet, but we cannot speak more definitely on this point. Dinosaur tracks have been reported from the red shales where they underlie a large tract of territory southeast of Reading.

Triassic igneous rocks. The sedimentary rocks (sandstone, shale and conglomerate) of the Triassic system are cut through here and there by igneous rocks of the nature of volcanic lava. These are basalt and diabase, dark gray to black, or greenish, heavy, dense material. They are supposed to have been forced up into or through the red beds along open cracks or between the several strata themselves. Sometimes they came out on the surface, again they stopped below ground and may today be exposed through the subsequent removal by erosion of the covering of sediments. Large bodies or *sills* lying parallel to the beds of sandstone and shale are recognized. Such appears to be the nature of those in Gibraltar and adjacent hills. Occasionally we find long, thin bands of these igneous rocks which cut "across lots" and occupy what were once cracks in the sediments. These are called *dikes.* Locally, one may see where the hot, fluid, igneous rocks came into contact with the surrounding sediments. At such places the sediments show the effect through change in color of being baked or "cooked."

The rocks of any age intermediate between the very young Pleistocene and Recent deposits and the relatively old Triassic are absent in our region just as are those between the Ordovician and Triassic. Some of the post-Triassic may be seen, though but poorly, in the neighborhood of Philadelphia, or in much more complete development in southern New Jersey.

PLEISTOCENE AND RECENT DEPOSITS

The great continental glacier or ice sheet of what is called Pleistocene time crept south across Pennsylvania, but never covered the entire State. It invaded northeastern Berks County about as far as Leesport, but spread no farther south or west. Because it failed to reach Reading, we need not devote further time to it or its direct influence, but merely refer those interested to published accounts, particularly that by Leverett (6), listed at the end of this bulletin. Nevertheless, the glacier affected the area indirectly; for, when it finally melted away, the water from the vanishing ice flooded the streams. Carried along in their swift currents, mud, sand and gravel were spread over lowlands in thick deposits far beyond the limit of the ice front. In Recent time, after the ice was gone, and the streams had dwindled to their present proportions, they no longer carried such enormous burdens. Instead of building up flood plains and river flats as they had done in the late glacial time, they began to cut down into the layers of mud, sand and gravel then formed, entrenching themselves in ever deepening valleys and leaving remnants of the old floodplains as terraces along the valley floors and sides.

Summarizing the stratigraphy, we have:

		Feet
PLEISTOCENE AND RECENT	Unconsolidated material, principally stream valley terraces	Variable
	Great stratigraphic break	

		Feet
TRIASSIC SYSTEM		
Brunswick formation	Red sandstone, shale and conglomerate cut by basic igneous rocks	5000 (?)
Great stratigraphic break		
ORDOVICIAN SYSTEM		
Martinsburg formation	Dark shale plus sandstones and thin limestone lenses	3000-4000
Leesport formation	Thin, platy limestone; variable lithology	50-60
Beekmantown formation	Massive, blue-gray, magnesian limestone	1000
CAMBRIAN SYSTEM		
Conococheague formation	Blue-gray, sandy, limestone with *Crytozoön* beds	1000-1500
Elbrook formation	Massive, blue-gray, magnesian limestone with chert bands ..	1000
Tomstown formation	Impure, dolomitic limestone and interbedded shale	800-1000
Hardyston formation	Sandstone, quartzite and conglomerate	300
PRE-CAMBRIAN ROCKS		
Pegmatites Byram granite and granite gneiss Pochuck dark gneiss		Variable

STRUCTURAL GEOLOGY

The structural relations of the Reading Hills are the subject of a geologic controversy at the present time so that final results cannot yet be given (5, 8, 13). All workers in the region agree on the general structure of the areas of Irish Mountain and northward across the limestone valley (see Figure 10). Here the main body of the mountain is composed of the pre-Cambrian Pochuck and Byram formations. Cambrian formations in orderly succession dip away from Irish Mountain and have their edges exposed as roughly parallel bands along the lower slopes and beyond in the valley. These bands consist of the Hardyston, Tomstown, Elbrook and Conococheague formations successively, in ascending order from south to north.

Two views of the structures south of Irish Mountain in the Mount Penn-Deer Path Hill ridge, have been presented (Figure 10). One view (13) is that the pre-Cambrian rocks (with some associated Hardyston and Tomstown material) now found in the area east and northeast of Reading have been thrust over the Reading area from a place some miles to the southeast. This theory implies that in this district younger rocks lie under the pre-Cambrian crystalline formations. A second view (8) is that the pre-Cambrian rocks are exposed in the Reading area and northeastward because the limestones, shales and sandstones that were deposited on these older formations have been eroded from the higher areas of crystalline rocks, where such rocks have been differentially uplifted by folding or by movement along steeply dipping faults. This theory implies that only pre-Cambrian rocks are present at depth in Mount Penn, Deer Path Hill and similar ridges.

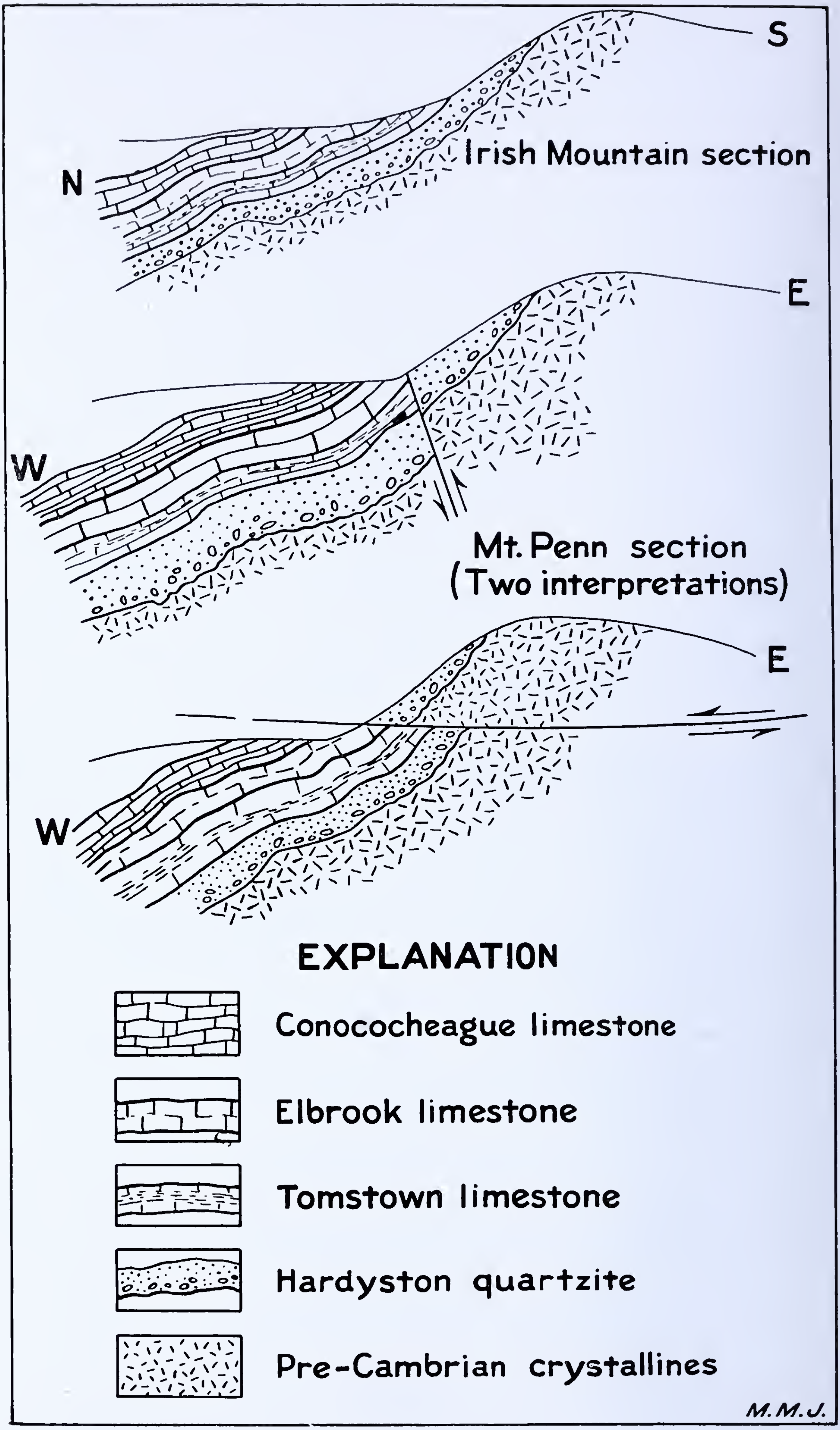

Figure 10—Comparative sections showing the simple structure at Irish Mountain, and two possible interpretations of the more complex structure in Mount Penn. In each section figured the same formations are involved.

Aside from this major structural problem of the area there is general agreement. The pre-Cambrian rocks are extensively jointed and in many places slipping along joints has produced displacement between blocks. The Cambrian and later Paleozoic sediments are both faulted and folded so that, although these sedimentary rocks lay once horizontally or nearly so, they are now tilted at all angles. In general the Cambrian beds dip northward or northwestward away from the mountain and under the successively younger beds in the broad valley to the north.

The Triassic red beds show some faulting, but little or no folding. This is in sharp contrast with the Paleozoic formations north of them. The reason for so striking a difference is that an interval of folding that affected the older rocks occurred after these Paleozoic formations (Cambrian, Ordovician and later) had been formed, but prior to the laying down of the Triassic strata. This interval of folding marked the inception of our Appalachian Mountains, and is called the Appalachian Revolution (1, 15).

GEOLOGIC HISTORY

The geologic history of the Reading region is a long and varied sequence of events which the geologist determines or infers from his studies of the rocks. Only, however, by studying them over a wide area can we interpret much of what we shall see locally on our trip (1, 2). In the foregoing sections on stratigraphy and structural geology, we told of the different kinds of rocks present and their dislocations. The events which produced these may now be considered.

Geologically, the history of the area began not later than 800,000,000 years ago. Probably some scores or even a few hundreds of millions of years before this the basic, dark-colored rocks whose remnants we see in the Pochuck gneiss, were metamorphosed and then were invaded by the magmatic material of the Byram. These processes may have been in more or less continuous operation over a period of 200,000,000 years. During the latter part of this long time the intimate mixing of the Pochuck and Byram occurred. Pegmatitic invasions followed, and pre-Cambrian time closed with an extensive erosional interval during which the upraised older formations that formerly were thousands of feet below the surface were exposed.

In somewhat less ancient times than the pre-Cambrian, called by geologists the Paleozoic era, a landmass of unknown eastward extent lay along what is now the eastern border of the United States, the region of today's coastal plain and continental shelf. West of this land, called conveniently *Appalachia,* was an inland sea. The old sea spread broadly over much of the interior of North America. In it the sediments that form the rocks belonging to the Paleozoic system were gradually deposited. Such was the geography (strictly speaking, the "paleogeography") during the Cambrian and Ordovician periods when the sediments of these ages found in the Reading Quadrangle were formed. The landmass was composed of the very ancient, pre-Cambrian, crystalline rocks. Some of these are today exposed as the

granite, gneiss, and related rocks of the Reading Prong. Their history has been discussed.

With the opening of the Cambrian period, the first major time division of the Paleozoic era, the sea lapped eastward upon the shores of Appalachia, and, as in our modern oceans, sea beaches made of sand and pebbles developed. These today are preserved in the Hardyston quartzite and sandstone which crop out in Mount Penn and Neversink Mountain. The coarseness of the sands implies that Appalachia was at least hilly so that its westward-running rivers carried sand and gravel seaward for waves and currents to catch up and spread as beach or continental shelf and bottom deposits.

When continental shores stand high and rivers run swiftly seaward, sand and gravel are borne down the water courses. As lands are worn lower, sand and mud or only mud constitutes the rivers' visible load of sediment. A yet lower relief may produce so little sediment that the amount entering the sea is negligible. Evidently, the relative coarseness of the river-to-sea borne sediment is an expression of the relief of the land. As a correlary of this, the greater the relief, the more active the streams. The sediments deposited near shore will vary in coarseness as in abundance from those laid down at more remote points. The farther off-shore, the less and finer are the sediments generally deposited on the sea bottom. At the beach are gravel and sand. Fine sands occur farther out; beyond these mud; and still more remote from shore, limy mud or ooze formed by life processes or chemical precipitation with little or no sand or mud (clastic sediments) from the land.

After deposition of the Lower Cambrian sandstones, the land was lowered or perhaps the shore-line shifted farther east. At any rate, the succeeding Tomstown limestone shows, by its shaly nature, that only mud was entering the sea from the adjacent, perhaps fairly remote land. This mud mingled with limy ooze. A step further is seen in the thick Elbrook, Conococheague and Beekmantown limestones which have only a small percentage of shale or sandy beds. In these we may visualize a situation in which only a small amount of clastic sediments reached the sea floor.

Toward the close of Beekmantown time, a change occurred, a change which reversed the process so far recorded. In the Leesport limestone we find shale interbedded with the calcareous layers. Either the coast was less remote, or the land had risen; and streams were once more actively transporting mud to the inland ocean. Probably, the re-elevation of the land was the cause, for almost at once, geologically speaking, the sea received a deluge of muddy and sandy water from the land. These sediments settled far and near as the Martinsburg sandstones and shales.

Of post-Martinsburg history during the Paleozoic, our area is a blank record in that any formations that may have been laid down here were eroded long ago. We may assume that many thousands of feet of such did accumulate here just as they did in central Pennsylvania, but today nothing remains of them. Toward the close of the Paleozoic era the sea filled up and dry land occupied the central

part of North America. Subsequently, the rock layers in the eastern part of the United States were subjected to squeezing and folding so that they bent and broke (faulted) from Vermont to Alabama. This movement is called the Appalachian Revolution because it was at this time that the faulting and folding of the rocks of the Appalachian Mountains took place. Then our Cambrian and Ordovician limestones and the Martinsburg shale were folded and the complex fault pattern of the older crystallines developed. The folding lifted the old sea floor high in the air. Simultaneously, old Appalachia sank low. Conditions were reversed. Where once the rivers of Appalachia flowed west into the inland sea, streams from the new highland began to flow eastward across piedmont plains and down-faulted segments of the earth's crust, eventually, we presume, to enter the still more distant Atlantic Ocean or its ancestor.

The eastward-flowing streams began to make a new system of sediments, the red Triassic sandstones, shales and conglomerates. They formed, not in the sea, but on land, for they contain foot-tracks of air-breathing reptiles, fossil land-dwelling invertebrates, and the remains of land plants. As corroborative evidence, their red color is usually looked upon as indicating a fresh-water environment at the time of origin. Incidentally, the limestone pebbles in the Triassic conglomerates came from the Cambrian and Ordovician limestones to the north and show that that region was being rapidly eroded and the products distributed to the south. About the close of Triassic time, hot lava from deep in the earth's crust welled up among the red beds; sometimes it found a crack to the surface and spilled over across the landscape; again, it forced its way between adjacent beds of sediment and so rose toward daylight. Solidified and cold, these lavas or traps (basalt and diabase) are today our higher Triassic hills.

Following the Triassic period is another long, local blank in geologic history. No more direct evidence of happenings is had until the time of the Pleistocene glacial period. The effects of that time, a recitation of recent happenings, and the development of the present topography and stream patterns have been described in the section on Physiography.

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DETAILED ITINERARY*

Miles

0.0 START. West side of Reading High School on North Thirteenth Street. Proceed south.

0.6 Right at end of N. 13th Street.

0.7 Left into Park. Continue through Park, south to Route 422 (Mineral Spring Ave.) The park is underlain by the Elbrook limestone.

1.1 Left into Mineral Spring Avenue (Route 422). Traffic stop street. Go east on Route 422 through Reiffton.

4.2 STOP 1. 10 minutes. Park cars right of highway. Road cuts expose Triassic "calico rock," a limestone conglomerate (fanglomerate) consisting of limestone pebbles in a red mud matrix. Continue east on Route 422.

* This schedule calls for an all-day trip, taking lunch along, and starting from the High School about 9 A. M.

5.1 Good exposure of "calico rock" on left. The road has emerged into the Triassic lowland. Across the river (south) are hills of Triassic "trap" rock.

5.9 After passing Reading Country Club on left, sharp left turn on black-top road up valley of Antietam Creek.

6.4 STOP 2. 15 minutes. Park cars right of road. Cuts expose Triassic red sandstone and shale. The contact of these sedimentary rocks with basic intrusive (diabase) rocks is seen here. The sediments next to the intrusion have been baked and discolored by heat. Variations in the character of the igneous rock may be seen. Continue north on same road to Jacksonwald.

7.9 Jacksonwald. Traffic stop street. Left on Route 562. Continue west through St. Lawrence.

9.2 Right from Route 562 on hard-surfaced road north toward Stony Creek Mills. We are crossing a limestone valley among belts of quartzite and pre-Cambrian crystalline rocks.

10.4 Left turn.

10.8 Right turn. The mountain to the west is of pre-Cambrian rock.

11.0 Left turn, and then right up creek on black-top road.

11.5 Right fork across bridge.

11.7 Stop 3. 20 minutes. Antietam Reservoir. Park cars around bend, first fork above dam. Observe exposure of pre-Cambrian igneous rocks. The light-colored ones are granite or granite gneiss, the dark rock is diorite-gabbro. Which is the older? What minerals are to be found in the granite? Note the pink and white pegmatitic masses cutting the other formations, also the small pegmatite dikes following joints in the Pochuck basic gneiss. Note slickensides where the rocks have broken and slipped over each other, also the well-developed joints opposite the dam. Turn about and retrace route south past dam.

11.9 Right, below dam and continue northwest past reservoir toward McKnights Gap.

12.3 Note boulders of gneiss on left slope.

13.1 Right turn. Boulders of Pochuck gneiss appear in the stone fence to the right.

13.6 Right turn.

13.8 McKnights Gap. Left on hard road along ridge toward Tower Hotel. Quartzite is exposed at left and at various places along the drive. Note the loose stone walls made of this rock.

15.7 STOP 4. 25 minutes. Mount Penn. Park right of road in space provided. The exposed rock east of road is Cambrian quartzite, the Hardyston formation. Note the bedding, dipping to the west. Here the formation is a sandstone-quartzite, but in other places is a conglomerate-quartzite. Also observe the joints, and the character of the grains as compared with sandstone. From the parking space a splendid view is obtained on clear days of the limestone valley stretching west, the shale hills at its borders, Triassic lowland Kittatinny, North or Blue Mountain on the northern horizon, and other features. The physiography may be discussed here. Turn about and retrace route north toward Tower Hotel.

16.0 STOP 5. 60 minutes. Park in city parking space at Tower Hotel. LUNCH PERIOD. Refreshment stand at the Tower. After lunch proceed north toward McKnights Gap.

17.7 McKnights Gap. Left fork and then right fork down grade on road toward Bernhart Reservoir. The road crosses loose material from the weathered bedrock of the mountain.

18.3 Right onto concrete highway at foot of hill.

18.4 Left fork.

18.9 Keep to left.

19.1 STOP 6. 15 minutes. Bernhart Reservoir. Park at right of road opposite dam. Walk across dam and bridge to exposure of pre-Cambrian gneiss. Leaving the reservoir, continue west toward Muhlenberg.

19.7 Right fork across trolley tracks.

20.2 Right onto Route 222 (Stop street). Continue north on Route 222 (Allentown road).

21.8 STOP 7. 15 minutes. Park cars right of concrete highway.
N.B. If the party is small, drive across concrete and park in secondary road west of highway. Visit rim of large quarry in Cambrian limestone. Note bedding, joints, gentle folds, residual soil, weathering, method of quarrying and use of rock. Return to cars and continue north to Maiden Creek village.

25.9 Left at Maiden Creek village onto Route 383 toward Ontelaunee Lake.

27.8 STOP 8. 15 minutes. Ontelaunee Lake and dam. Crossing bridge, park left on space provided. Observe method of damming creek for water supply, dam built on rock, spillway, etc. Return to cars and continue west.

28.7 Right onto Route 122, Pottsville Road (Stop street) and proceed north to Leesport. At Leesport the limestone valley ends against the higher ground underlain by the Martinsburg formation.

29.9 Leesport. Left onto Route 383 toward West Leesport.

30.3 STOP 9. 15 minutes. West Leesport. Park cars right of highway at freight station. Observe cut across tracks. It will not be necessary to go upon the railroad. Exposure shows the Martinsburg (Ordovician) shale and sandstone in contact with older, Ordovician platy and massive limestones, the Leesport. Observe folding and faulting. Continue west on Route 383.

35.8 Obold. Left onto Route 83. Continue south on Route 83 to Reading. The road crosses Martinsburg shale for several miles.

43.7 In Reading. Right onto Route 422 at east end of viaduct. Traffic light. Party should move slowly across bridge to allow for any "caught on the red" to catch up. Note the black color of the Schuylkill choked with anthracite washings.

45.3 Right from 422 beyond traffic light at Wyomissing Boulevard onto Bern Road.

45.7 STOP 10. 30 minutes. Park cars right of road before reaching stone arch bridge at R.R. Walk north under arch and right to an abandoned shale brick quarry. Here are exposed the massive Beekmantown limestone and deeply weathered, altered Martinsburg shale, both of Ordovician age. Note shearing, bedding, weathering, residual soil, quartz veins, etc. Party disbands here.

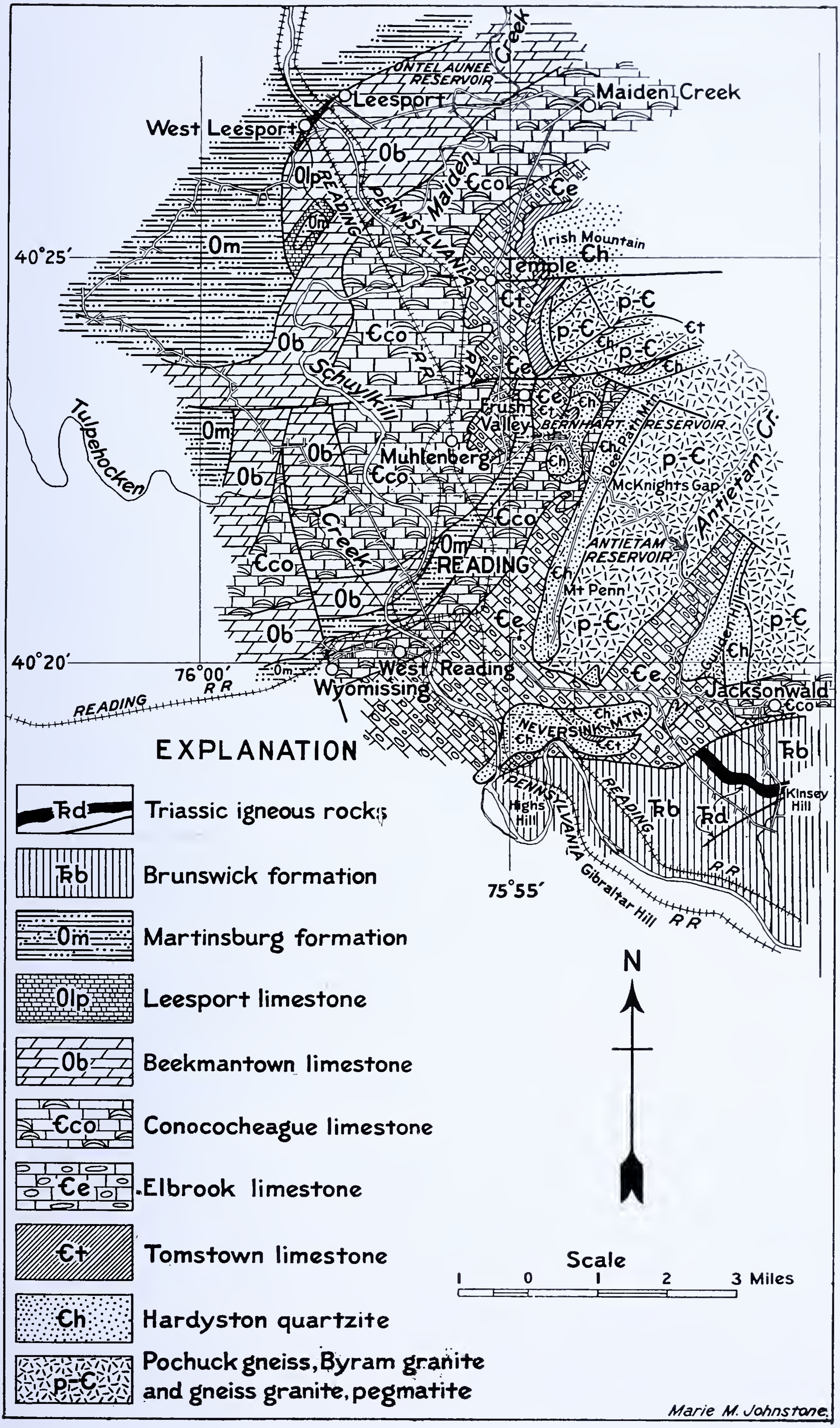

Figure 11—Geologic map of the Reading area. The route of the itinerary is indicated.